Extended Aging of RAS Mixes with Rejuvenator

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Mathy Construction

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Acknowledgements

• MTE Staff
  – Mary Ryan, Doug Herlitzka, and Steve Engber

• Mathy Construction Staff
  – John Jorgenson and Chad Lewis
Motivation

• Cracking is the most prominent state agency concern
  – High levels of binder replacement, especially from RAS can cause durability concerns.
  – Materials used to soften asphalt can have unintended consequences.

• These risks aren’t apparent until after long-term aging.

• Evaluate different long-term aging methods.
Background

• Current long term aging protocols in specifications
  – Binder (M320/M332): 1 PAV aging cycle.
  – Mix (R30): 5 days compacted mix aging at 85°C

• This study focuses on extended aging. Why?
  – Identify aging susceptible materials in the mix (RAS) or binder (softening additives).
  – Under current specifications most of these materials appear acceptable.
Why do we need long term aging?

MnRoad (1999) Binder Grade Study

4 year & 5.5 year Crack Results = F(ΔTc 10 Day, 85°C Aged Mix)

PG 58-28, PG 58-34, and PG 58-40 Binders selected. The PG 58-40 performed the worst.

Total Cracks (Non-CL) after 4 years in-service
Total Cracks (Non-CL) after 5.5 years in service
Mix Aging Study

Objectives

1. Compare aging stability of bio-based rejuvenator modified binders to conventional PG asphalt.
2. Evaluate effects of multiple aging methods and conditioning times on physical properties and composition.
Mix Aging Study

Materials

• RAS: Tear-off shingles from a commercial source in Central-WI (TOS #1)
• Asphalt: PG 58-28 and PG 52-34 sampled from MIA.
• Additives:
  – Experimental Product (EP #1)
  – Bio-based Oils (BO #1 and BO #2)
• Blends
  – PG 58-28 + 5% bio oil was used to target a final grade of PG 52-34.
# Mix Aging Study

## PG of Binder Blends

<table>
<thead>
<tr>
<th>Blend</th>
<th>HT PG (Unaged)</th>
<th>LT PG 20hr PAV</th>
<th>LT PG 40hr PAV</th>
<th>ΔTc 20 hr PAV</th>
<th>ΔTc 40 hr PAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 52-34</td>
<td>54.0</td>
<td>-35.3</td>
<td>-32.2</td>
<td>0.5</td>
<td>-1.9</td>
</tr>
<tr>
<td>PG 52-34 + 5% EP#1</td>
<td>52.7</td>
<td>-34.2</td>
<td>-32.7</td>
<td>0.56</td>
<td>0.61</td>
</tr>
<tr>
<td>PG 52-34 + 2.5% BO#1 + 5% EP#1</td>
<td>48.3</td>
<td>-36.5</td>
<td>-35.6</td>
<td>1.6</td>
<td>0.4</td>
</tr>
<tr>
<td>PG 58-28</td>
<td>59.6</td>
<td>-29.7</td>
<td>-25.1</td>
<td>-0.2</td>
<td>-3.1</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#1</td>
<td>51.2</td>
<td>-36.5</td>
<td>-33.3</td>
<td>-0.4</td>
<td>-1.5</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#2</td>
<td>49.3</td>
<td>-36.2</td>
<td>-33.1</td>
<td>0.6</td>
<td>-0.5</td>
</tr>
</tbody>
</table>
**Mix Aging Study**

**RAS Binder Properties**

<table>
<thead>
<tr>
<th>RAS Binder</th>
<th>R – value</th>
<th>HT PG</th>
<th>LT PG</th>
<th>ΔTc</th>
<th>S(60)</th>
<th>m(60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOS #1</td>
<td>6.03</td>
<td>146</td>
<td>6.0</td>
<td>-31.4</td>
<td>-25.4</td>
<td>6.0</td>
</tr>
</tbody>
</table>

- RAS AC content = 22.1%
- All mixes used in this study included 5% RAS by weight.
Mix Aging Study

Mix Design

• Mix represents a normal surface course used for intermediate traffic levels in WI.
  – Design Traffic Level: 3 million ESALs (E3), 75 gyrations for Ndes.
  – NMAS: 12.5 mm

• Aggregate Source: Granite + 25% nat. sand

• Gradation: Fine, 70% passing the #4 sieve.

• Design AC: 5.7% (19.4% binder replacement from RAS)
## Mix Aging Study
### Aging Methods

<table>
<thead>
<tr>
<th>Aging Method</th>
<th>Aging Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose Mix + PAV</td>
<td>As-Recovered (after 2 hrs at 135°C)</td>
</tr>
<tr>
<td></td>
<td>As-Recovered + PAV (Blending Chart)</td>
</tr>
<tr>
<td></td>
<td>As-Recovered + 2PAV</td>
</tr>
<tr>
<td>Loose Mix</td>
<td>12 hrs at 135°C</td>
</tr>
<tr>
<td></td>
<td>24 hrs at 135°C</td>
</tr>
<tr>
<td>Compacted Mix</td>
<td>5 days at 85°C (AASHTO R30) – <strong>Test results pending</strong></td>
</tr>
<tr>
<td></td>
<td>10 days at 85°C</td>
</tr>
<tr>
<td></td>
<td>20 days at 85°C</td>
</tr>
</tbody>
</table>
Mix Aging Study

Description of Work

• After the prescribed aging protocol asphalt binder was extracted and recovered from mix.

• Recovered residue evaluated using:
  – DSR: 25 mm and 4mm Parallel Plate
  – Iatroscan: Determine composition

• Future work will use torsion bar modulus on compacted mix samples.
Mix Aging Study
Effects of Additives and Aging on Physical Properties

- Low Temperature Properties: PG grade
- Durability: \( \Delta T_c \)

**Two Analysis Cases**

1. Softer Binder Grade vs. Rejuvenating additives
   - Control: PG 52-34
   - PG 52-34 +5% EP#1 and PG 52-34 +2.5% BO#1 + 5% EP#1
   - PG 58-28 modified with 5% BO#1 and BO#2. Target grade for modification is PG 52-34.

2. Do nothing alternative
   - Compare PG 58-28 to the PG 58-28 modified asphalts in Case #1.
4mm DSR for Determining $\Delta T_c$ & LT PG

Direct Measurement – 4mm PP

**Effect of Aging**

- $\eta_0$ vs. Reduced Frequency, rad/s
- $G_0$ vs. Reduced Frequency, rad/s

**Rheological Index (R)**

<table>
<thead>
<tr>
<th>Binder/LT PG Grade</th>
<th>20% RAS + 5% Oil 1</th>
<th>20% RAS + 5% Oil 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTFO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAV1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAV2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PG Grading**

## Results – Case #1 Summary – LT PG

<table>
<thead>
<tr>
<th>Binder</th>
<th>Intermediate Aging</th>
<th>Extended Aging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 hr PAV</td>
<td>12 hr Loose</td>
</tr>
<tr>
<td>PG 52-34</td>
<td>-32.8</td>
<td>-31.1</td>
</tr>
<tr>
<td>PG 52-34 + 5% EP#1</td>
<td>-33.5</td>
<td>-31.0</td>
</tr>
<tr>
<td>PG 52-34 + 2.5% BO#1+5% EP#1</td>
<td>-36.2</td>
<td>-33.6</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#1</td>
<td>-32.6</td>
<td>-29.3</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#2</td>
<td>-33.1</td>
<td>-26.2</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>-33.6</strong></td>
<td><strong>-30.2</strong></td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td><strong>-32.6</strong></td>
<td><strong>-26.2</strong></td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td><strong>-36.2</strong></td>
<td><strong>-33.6</strong></td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td><strong>3.68</strong></td>
<td><strong>7.42</strong></td>
</tr>
</tbody>
</table>
Data Plots

• Reference was taken after loose mix aging at 135°C (standard mix design protocol)

• Each aging type was assigned a different line style:
  – Binder aging: Solid Line
  – Loose Mix Aging: Dotted Line
  – Compacted Mix Aging: Dashed Line

• Two aging conditions defined:
  – Intermediate: AC Recovery + PAV, 12 hr loose mix, and 10 day compacted mix
  – Extended: AC Recovery + 2PAV, 24 hr loose mix, 20 day compacted mix.
Results – Case #1

PG 52-34

Recovered AC from Mix Design

20 hr PAV
12 hr Loose Mix Aging
10 Day Compacted Mix Aging

40 hr PAV
24 hr Loose Mix Aging
20 Day Compacted Mix Aging

LT PG (°C)

PAV Plot = 2 hr STOA, 20 & 40 hr PAV results
Compacted Plot = 2 hr STOA, 10 & 20 day @ 85°C
Loose Plot = 2 hr STOA, 12 & 24 hr @ 135°C
## Results – Case #1 LT PG

PG 52-34, PG 52-34 + EP#1, PG 58-28 + BO#1

<table>
<thead>
<tr>
<th>LT PG (°C)</th>
<th>Recovered AC from Mix Design</th>
<th>20 hr PAV</th>
<th>40 hr PAV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 hr Loose Mix Aging</td>
<td>24 hr Loose Mix Aging</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 Day Compacted Mix Aging</td>
<td>20 Day Compacted Mix Aging</td>
<td></td>
</tr>
</tbody>
</table>

- **Recoverd AC from Mix Design**
- **20 hr PAV**
- **40 hr PAV**

**Legend:**
- 52-34 PAV
- 52-34 Loose
- 52-34 + EP#1 PAV
- 52-34 + EP#1 Compactted
- 52-34 Compactted
- 52-34 + EP#1 Loose
- 52-34 + EP#1 Compactted
- 58-28 + BO#1 PAV
- 58-28 + BO#1 Compactted

**Note:**
- PAV Plot = 2 hr STOA, 20 & 40 hr PAV results
- Compacted Plot = 2 hr STOA, 10 & 20 day @ 85°C
- Loose Plot = 2 hr STOA, 12 & 24 hr @ 135°C
Results Case #1

LT PG - Intermediate Aging

-20.0
-22.0
-24.0
-26.0
-28.0
-30.0
-32.0
-34.0
-36.0
-38.0

-Δ = 3.7°C

20 hr PAV

12 hr Loose

10 Day Compacted

Δ = 7.4°C

Δ = 8.1°C

PG 52-34
PG 52-34 + 5% EP#1
PG 52-34 + 2.5% BO#1+ 5% EP#1
PG 58-28 + 5% BO#1
PG 58-28 + 5% BO#2
Results Case #1
Extended Aging

<table>
<thead>
<tr>
<th></th>
<th>40 hr PAV</th>
<th>24 hr Loose</th>
<th>20 Day Compacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT PG (°C)</td>
<td>-35.0</td>
<td>-30.0</td>
<td>-25.0</td>
</tr>
<tr>
<td>PG 52-34</td>
<td>-20.0</td>
<td>-15.0</td>
<td>-10.0</td>
</tr>
<tr>
<td>PG 52-34 + 5% EP#1</td>
<td>-15.0</td>
<td>-10.0</td>
<td>-5.0</td>
</tr>
<tr>
<td>PG 52-34 + 2.5% BO#1 + 5% EP#1</td>
<td>-20.0</td>
<td>-15.0</td>
<td>-10.0</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#1</td>
<td>-25.0</td>
<td>-20.0</td>
<td>-15.0</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#2</td>
<td>-30.0</td>
<td>-25.0</td>
<td>-20.0</td>
</tr>
</tbody>
</table>

\[ \Delta = 5.2°C \]
\[ \Delta = 13.5°C \]
\[ \Delta = 9.8°C \]
Case #1 Summary

LT PG

• PAV aging at both conditions did not discriminate between materials as well as loose mix or compacted mix aging.
• EP#1 maintained better low temperature grading relative to PG 52-34 control and other additives, even with extended aging.
• Combination of EP#1 and BO#1 performed best.
• No benefit of additives observed in maintaining low temperature PG with extended aging. BO #2 was worst in most categories, PG 52-34 was marginally better than BO #1 at intermediate aging and substantially better after extended aging.
## Results – Case #1 Summary

### ΔTc

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Intermediate Aging</th>
<th>Extended Aging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 hr PAV</td>
<td>12 hr Loose</td>
</tr>
<tr>
<td>PG 52-34</td>
<td>-2.6</td>
<td>-2.8</td>
</tr>
<tr>
<td>PG 52-34 + 5% EP#1</td>
<td>-0.7</td>
<td>-1.8</td>
</tr>
<tr>
<td>PG 52-34 + 2.5% BO#1+5% EP#1</td>
<td>-0.2</td>
<td>-1.9</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#1</td>
<td>-3.1</td>
<td>-4.1</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#2</td>
<td>-1.6</td>
<td>-5.3</td>
</tr>
<tr>
<td>Average</td>
<td>-1.6</td>
<td>-3.2</td>
</tr>
<tr>
<td>Max</td>
<td>-0.2</td>
<td>-1.8</td>
</tr>
<tr>
<td>Min</td>
<td>-3.1</td>
<td>-5.3</td>
</tr>
<tr>
<td>Range</td>
<td>2.91</td>
<td>3.49</td>
</tr>
</tbody>
</table>
Results – Case #1 $\Delta T_c$

**PG 52-34, PG 52-34+EP#1, PG 58-28+BO#1**

<table>
<thead>
<tr>
<th>Recovered AC from Mix Design</th>
<th>20 hr PAV</th>
<th>40 hr PAV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 hr Loose Mix Aging</td>
<td>24 hr Loose Mix Aging</td>
</tr>
<tr>
<td></td>
<td>10 Day Compacted Mix Aging</td>
<td>20 Day Compacted Mix Aging</td>
</tr>
</tbody>
</table>

- **Recoved AC from Mix Design**
- **52-34 PAV**
- **52-34 Compacted**
- **52-34 Loose**
- **52-34 + EP#1 PAV**
- **52-34 + EP#1 Compacted**
- **52-34 + EP#1 Loose**
- **58-28 + BO#1 PAV**
- **58-28 + BO#1 Compacted**
- **58-28 + BO#1 Loose**
Summary of Results

Intermediate Aging

<table>
<thead>
<tr>
<th></th>
<th>ΔTc (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 hr PAV</td>
<td>Δ = 2.6°C</td>
</tr>
<tr>
<td>12 hr Loose</td>
<td>Δ = 3.5°C</td>
</tr>
<tr>
<td>10 Day Compacted</td>
<td>Δ = 2.9°C</td>
</tr>
</tbody>
</table>

- PG 52-34
- PG 52-34 + 5% EP#1
- PG 52-34 + 2.5% BO#1 + 5% EP#1
- PG 58-28 + 5% BO#1
- PG 58-28 + 5% BO#2
Summary of Results

Extended Aging

\[ \Delta = 3.5^\circ C \]

\[ \Delta = 6.0^\circ C \]

\[ \Delta = 9.9^\circ C \]
Observations

• Significant differentiation was observed after extended aging, particularly loose mix.
• EP#1 improved $\Delta T_c$ at all aging conditions.
• BO#1 and BO#2 resulted in worse values of $\Delta T_c$ relative to using a softer binder grade.
Case #2
“Do Nothing” Alternative

• Evaluate the effectiveness of using rejuvenators vs. not changing PG.
  – Control: PG 58-28
  – Additives: PG 58-28 + BO#1 and PG 58-28+BO#2

• Target climate for mix is -28°C
Case # 2 Summary LT PG

Intermediate Aging

<table>
<thead>
<tr>
<th>LT PG (°C)</th>
<th>20 hr PAV</th>
<th>12 hr Loose</th>
<th>10 Day Compacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58-28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG 58-28 + BO#1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG 58-28 + BO#2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case #2 Summary LT PG

Extended Aging

40 hr PAV | 24 hr Loose | 20 Day Compacted

LT PG (°C)

PG 58-28
PG 58-28 + BO#1
PG 58-28 + BO#2
Case #2 Summary $\Delta T_c$

Intermediate Aging

<table>
<thead>
<tr>
<th></th>
<th>20 hr PAV</th>
<th>12 hr Loose</th>
<th>10 Day Compacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T_c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG 58-28</td>
<td>-3.0</td>
<td>-5.0</td>
<td>-5.0</td>
</tr>
<tr>
<td>PG 58-28 + BO#1</td>
<td>-3.0</td>
<td>-5.0</td>
<td>-5.0</td>
</tr>
<tr>
<td>PG 58-28 + BO#2</td>
<td>-3.0</td>
<td>-5.0</td>
<td>-5.0</td>
</tr>
</tbody>
</table>
Case #2 Summary $\Delta T_c$

Extended Aging

$\Delta T_c$ (°C)

-18.0  -16.0  -14.0  -12.0  -10.0  -8.0  -6.0  -4.0  -2.0  0.0

40 hr PAV  24 hr Loose  20 Day Compacted

PG 58-28  PG 58-28 + BO#1  PG 58-28 + BO#2
Case #2 Observations

• Diminishing returns in using rejuvenating additives.
  – ΔTc: No significant benefit of additives for most aging conditions.

• Extended aging needed to evaluate additives used to soften the binder.
## Comparison of Aging Methods

### SARA Analysis

<table>
<thead>
<tr>
<th>Aging Method</th>
<th>Asphaltenes</th>
<th>Resins</th>
<th>Cyclics</th>
<th>Saturates</th>
</tr>
</thead>
<tbody>
<tr>
<td>52-34, 5% RAS, 12 hr loose</td>
<td>27.2</td>
<td>30.0</td>
<td>34.3</td>
<td>8.9</td>
</tr>
<tr>
<td>52-34, 5% RAS, 24 hr loose</td>
<td>32.6</td>
<td>29.2</td>
<td>28.7</td>
<td>9.5</td>
</tr>
<tr>
<td>52-34, 5% RAS, 20 day compacted</td>
<td>28.0</td>
<td>33.9</td>
<td>29.8</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Comparison of Aging Methods

Colloidal Index vs. R-Value

\[ y = 5.8444x^{-1.058} \]

\[ R^2 = 0.9255 \]

<table>
<thead>
<tr>
<th>R Value</th>
<th>Colloidal Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.50</td>
<td>1.00</td>
</tr>
<tr>
<td>3.00</td>
<td>1.20</td>
</tr>
<tr>
<td>3.50</td>
<td>1.40</td>
</tr>
<tr>
<td>4.00</td>
<td>1.60</td>
</tr>
<tr>
<td>4.50</td>
<td>1.80</td>
</tr>
<tr>
<td>5.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

- 52-34, 5% RAS, 12 hr loose
- 52-34, 5% RAS, 24 hr loose
- 52-34, 5% RAS, 20 day compacted
- 58-28, 5% RAS, 12 hr loose
- 58-28, 5% RAS, 24 hr loose
- 58-28, 5% RAS, 20 day compacted
- 58-28, 5% BO#2, 5% RAS, 12 hr loose
- 58-28, 5% BO#2, 5% RAS, 24 hr loose
- 58-28, 5% BO#2, 5% RAS, 20 day compacted
MnRoad/WRI Binder Source Study
Olmstead County (2006)

• How do laboratory aging protocols evaluated relate to the field?
• Study commissioned to evaluate the effect of asphalt binder source on performance.
• Control section was PMA PG 58-34 + 20% RAP.
• Test sections were virgin mixes, with the following binder sources.
  – MN 1-2: PMA PG 58-34
  – MN 1-3: PG 58-28 Canadian Blend
  – MN 1-4: PG 58-28 Middle Eastern Blend w/REOB
  – MN 1-5: PG 58-28 Venezuelan

• No mixes contained RAS.
Laboratory vs. Field Aging (Reinke, 2015 ETG)

Loose Mix

- 8 yr field aged vs. 12 hour loose mix aging at 135°C
- 8 yr field aged vs. 24 hour loose mix aging at 135°C

To represent 8 years field aging – laboratory aging at 135°C falls between 12 and 24 hours.
Laboratory vs. Field Aging (Reinke, 2015 ETG)

Binder

\[ \Delta T_c \] after 20 hour PAV

\[ \Delta T_c \] after 40 hour PAV
Conclusions

• Aging Methods
  – Both compacted mix and loose mix aging methods were more severe than PAV aging. Related to film thickness?
  – Presence of RAS impacted extended aging behavior. In MnDOT study 40 hr PAV and 24 hr loose mix aging were similar, for the RAS mixes differences were significant.
  – 12 hr loose mix aging and 10 day compacted mix aging produced similar results. 24 hour aging was very severe and could not be replicated by any other aging protocols.

• RAS:
  – Mix aging methods showed a significant deterioration of properties with extended aging.
  – Revisions to PP78 were intended to address RAS durability risks, PAV vs. mix aging issue requires further investigation.
Conclusions

• Rejuvenating Additives
  – EP#1 demonstrated an ability to retard aging. Low temperature PG and $\Delta Tc$ were better relative to the PG 52-34 across multiple aging conditions.
  – The softening effects of BO#1 and BO#2 diminished with aging, $\Delta Tc$ was worse than the PG 52-34.
  – When compared to the “do nothing” alternative of using PG 58-28 with RAS mixes, similar $\Delta Tc$ values were observed after aging. LT PG was within ~one grade.
Future Work

• Finish Current Study
  – Compacted mix aging after 5 pending.
  – Chemical analysis.

• Expand Mixes Tested
  – Lower RAS loadings (i.e. 3%)
  – Designs with high RAP and conventional RAP dosages.

• Verify extracted binder results
  – Torsion bar testing and analysis.
Thank You!

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